# Alternative structures for a Hydro Action Decision Tree (Draft for SRP review)

**Calvin Peters**
**Dave Marmorek**
**Rick Deriso**

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## Introduction

Decision analysis is a formal method used to facilitate decision-making by organizing all relevant information into a systematic framework. There are several features of decision analysis that makes it a useful tool for PATH:

- incorporates multiple alternative hypotheses
- requires uncertainties to be explicitly (quantitatively) represented
- able to systematically incorporate professional judgments about key hypotheses and their uncertainties
- ranks alternative management actions using a variety of performance measures
- links quantitative analyses directly into the decision-making process

These features, as well as recommendations by Saul Saila and Carl Walters (SRP review of the Preliminary Report on Retrospective Analysis in April of 1996) and Randall Peterman (various PATH workshops) to use decision analysis to quantitatively address key decisions in the Columbia River basin, provide the impetus for using this tool in PATH.

This is the third in a series of documents that provide some thoughts on how to structure a PATH decision analysis for Spring/Summer Chinook salmon. In the first of this series, “Applying Decision Analysis to PATH: Discussion Paper”, we set out some preliminary thinking on the structure and implementation of decision analysis in PATH, some alternative ways of approaching some major issues, and a simple example of the mechanics of decision analysis. The second document, “Tasks for PATH Decision Analysis of Spring/Summer Chinook”, provides an overview of the general plan for implementing decision analysis by outlining a suggested approach to decision analysis for Hydro, Habitat, Hatchery, and Harvest actions, as well as the tasks required to carry out this approach. This document expands on some of these tasks, providing greater detail on what information is required, identifying some of the issues associated with these tasks, and outlining various options for resolving these issues. Many of the ideas discussed below are based on discussions at various PATH technical meetings and at the last PATH Workshop held April 22-24, 1997. Task numbers provided correspond to the numbering scheme used in the “Tasks for PATH Decision Analysis” document and in the FY97 PATH Task list.

As a framework for this discussion, we have developed a prototype decision tree (Figures A1-1, A3-1) that summarizes the current state of thought on applying decision analysis to hydro actions. Further development and refinement of this tree will take place as the issues identified in this paper are resolved. Discussion of each of the 5 major components of the decision tree (Management actions, Models, Uncertainties, Probabilities, and Performance Measures) is provided below.

## Task 1.1 - Identify Management Actions

Eight sets of hydro management actions have been selected by the IT/PATH sub-group for analysis (Table 1). These 8 action sets represent different combinations of flow augmentation in the Columbia and Snake Rivers, different levels of transportation, natural river drawdown of the 4 lower Snake River dams, and natural river or spillway crest drawdown of John Day Dam.

Table 1. Hydro management actions

| | Flow Augmentation | | | |
|---|---|---|---|---|
| Scenario | Columbia | Snake | Drawdown of 4 Lower Snake dams | Drawdown of John Day Dam |
| A1 (Base case) | X | X | - | - |
| A2 | | | - | - |
| A3 | X | X | Natural River | - |
| A5 | X | - | Natural River | - |
| B1 | X | X | Natural River | Natural River |
| B2 | - | - | Natural River | Natural River |
| C1 | X | X | Natural River | Spillway Crest |
| C2 | - | - | Natural River | Spillway Crest |

Each action requires a particular set of hydroregulation model runs to provide input flows to the passage models. Development and coordination of these hydroreg runs is the responsibility of an ad hoc Hydroreg Workgroup, which has representatives from various agencies including the Army Corps of Engineers, BPA, and PATH. Initially, the decision analysis will only evaluate scenarios A1(Base Case; Figure A1-1) and A3 (Drawdown; Figure A3-1). Other scenarios will be evaluated as hydro regulation model results become available.

## Task 1.2 - Develop Passage Models

The passage models provide the main tool for simulating the effects of alternative management actions in the juvenile migratory corridor (JMC) life stage. Using two passage models to generate outcomes introduces an additional element of uncertainty into the decision analysis, since outcomes depend not only on uncertainties in the parameter values within each model, but also on differences in the structures, assumptions, and data sets between the two models

Before these models are used in the decision analysis, the passage modeling workgroup decided that it was important to try to standardize some of the input data (while still allowing for alternative hypotheses) to better understand the relative significance of differences in input data and differences in model assumptions. Workgroups are currently undertaking two tasks (Task 1.2.1 and 1.2.4) to accomplish this.

### Task 1.2.1 - Identify Standard Data Sets

A data set workgroup has been holding a series of technical meetings with representatives from both passage modeling groups to agree on key input data sets:

- flows
- Water Travel Time
- Fish Travel Time
- historical FGE's
- mortality due to passage through dams (turbine, spillway, and bypass)
- direct transportation mortality (i.e. in the barge)

**Task 1.2.4 - Compare updated CRiSP and FLUSH to reach survival data**

The passage modeling workgroup is conducting a model comparison exercise in which survival estimates obtained from both models (using the common data sets identified in the previous task) are compared to a common set of reach survival data. Initially, this approach was considered as a potential way for assigning probabilities to the two models for use in the decision analysis (see task 1.4). However, there are several issues associated with this exercise that complicate a rigorous quantitative comparison of the two models:

1. FLUSH is explicitly calibrated to a subset of these data.
2. What criterion/criteria should be used to quantify the comparison (e.g. regression of predicted reach survival vs. observed)?
3. How should the # of parameters in the models be considered in the comparison procedure?
4. A close match with historical data does not necessarily mean good predictive ability, since future conditions might lie outside the range of historical data (see Randall Peterman's comments in Appendix A on this topic).
5. Correctly predicting survival over many reaches with large reservoirs is more important than over 1 or 2 short reaches.

Because of these issues, it was decided that this model comparison exercise should not be used to assign probabilities. However, the group decided that a qualitative comparison could still provide some useful information about model differences and similarities.

**Task 1.2.5 Linkage between passage models and the Bayesian prospective model**

Because passage models simulate effects only in the JMC life stage, another model is needed to propagate those effects throughout the other life stages and calculate numbers of spawners for use in the NMFS Jeopardy Standards. One life-cycle model that has been developed for that purpose (Bayesian prospective model; BSM) is based on the Ch. 5 MLE analysis (FY96 Retrospective Report) and an iterative series of five workshops and technical meetings between October 1996 and April 1997. A detailed description of this model is available elsewhere (Deriso et al., "Prospective Analysis of Spring Chinook of the Snake River Basin"; submitted to the SRP in the first package June 3). However, additional versions of this type of model have recently been proposed and are under development by Anderson, Hinrichsen, and Paulsen. Descriptions of these models (Anderson et al, "Comparison of MLE Spawner-Recruit Models", and Anderson and Hinrichsen "A Suite of Alternative Hypotheses Using A Passage Model In a Bayesian Approach") and a comparison of their structures with the BSM stock-recruitment model will be submitted to the SRP for their comments in early July. Most of the remaining discussion focuses on BSM, but the basic issues need to be considered regardless of which prospective model is used.

The decision analysis framework that exists can incorporate one or more of these models. However, using multiple models within the decision analysis will add to its complexity and, consequently, the time and effort needed to perform the analysis. A much better approach would be to accommodate different hypotheses within a single modeling framework. A Prospective Modeling subgroup will be meeting the week of June 23rd to assess the potential for integration of the different approaches. The output of that meeting will be sent to the SRP with descriptions of recently developed alternatives to BSM in early July. We are looking to the SRP to help us decide which prospective models should be used in the decision analysis so that plausible alternative hypotheses can be considered without adding unnecessary or redundant analyses.

The mechanism for linking passage models to a prospective life-cycle model has not yet been fully developed. Two linkage options have been proposed (Table 2) for the BSM prospective model. One option (Linkage Option 1) is to have the passage models generate a vector or time series of passage mortality estimates for both transported and non-transported fish, then use this vector in BSM as one component of survival over the entire life cycle. This option would also work in other prospective life cycle models to the extent that they explicitly incorporate passage mortality estimates.

Another option (Linkage Option 2) is to have CRiSP and FLUSH produce the ratio of survival of transported fish ($S_T$) to the survival of non-transported fish ($S_N$), and the proportion of fish destined for transport ($P_T$) for each year. Then, given the overall survival rate S from the MLE analysis, $S_T$ and $S_N$ can be calculated from the equation:

$$S = [P_T + (1-P_T)S_N/S_T]S_T$$

These estimates of $S_T$ and $S_N$ would then be used in BSM to simulate overall survival. Note that this option essentially scales passage model estimates of survival for transported and non-transported fish to exactly match MLE estimates of overall survival, guaranteeing that passage model output will be consistent with the MLE analysis and the stock-recruit data

The survival and transport parameters are standardized to represent survival and transport of fish enumerated at the top of the first reservoir. The advantage of this type of standardization is that the ratio $S_T / S_N$ equals the transport control ratio (TCR) for the simple case of a single transport site. For the case of a single site, the passage models would provide estimates of $S_T$ which equal survival from the top of the first reservoir to point of transportation (times) survival of transported fish from point of transportation until return as recruits to the mouth of the Columbia River. Likewise, $S_N$ equals survival of fish not transported, as calculated from the top of the first reservoir until return as recruits to the mouth of the Columbia River. The BSM will scale those survival numbers to include delayed mortalities common to both transported and non-transported fish. Any differential delayed mortality between the transported and non-transported fish would need to be included in the ratio , $S_T / S_N$, just as one would find in observed TCR's.

In the case of multiple transport sites, the relationship between $S_T / S_N$ and TCR is not exact. In order to standardize the $S_T / S_N$ , one can follow a type of cohort analysis method; namely the number of fish destined to be transported , say $N_T$, equals $\Sigma N(j)/S(j)$ in which N(j) is number actually transported at site (j) and S(j) is survival from top of first reservoir to transport site (j) -- $S_T$ equals the ratio $(\Sigma R(j))/N_T$ in which R(j) is number of fish transported at site (j) that return as recruits to the mouth of the Columbia River. A similar analysis would facilitate calculations of fish destined for transport when there are multiple transport sites over multiple days for multiple cohorts; one simply adds up the ratios of numbers transported at each site on each day to survival for that cohort to that transport site/day category. The survival or non-transported fish equals

[Rtotal - (Σ R(j))]/[Ntotal - $N_T$] , that is, the number of non-transported recruits divided by number of fish not destined for transport.

The proportion of fish destined for transport $P_T$ is equal to the number of fish destined to be transported $N_T$ divided by Ntotal, the total number of fish that pass through the top of the first reservoir.

Table 2. Options for linking passage models to the BSM prospective model and implications for other components of the decision analysis (see tasks for further discussion).

| | **Linkage Option 1** | **Linkage Option 2** |
|---|---|---|
| Output of passage models (Task 1.2.5) | Vector of passage mortality estimates for $S_T$, $S_N$ | Ratio of $S_T$:$S_N$, $P_T$ |
| Representation of uncertainty in reservoir survival (Task 1.3.2.1) | Range of values for passage model parameters | Range of values for passage model parameters |
| Representation of uncertainty in post-BON survival (Task 1.3.2.2) | Explicit inclusion of alternative hypotheses into estimates of $S_T$, $S_N$ | Adjustment of $S_T$:$S_N$ to reflect alternative hypotheses |
| Spawner-recruit data (Task 1.4, Approach A) | Used to assign likelihoods to hypotheses chains | MLE model used to scale passage model output to match S-R data |
| Other data sets (Task 1.4, Approach B) | Used in conjunction with likelihoods to assign posterior probabilities to hypotheses | Used to directly assign posterior probabilities to hypotheses |
| Expert judgment (Task 1.4, Approach C) | Used in conjunction with likelihoods to assign posterior probabilities to hypotheses | Used to directly assign posterior probabilities to hypotheses |

Other mechanisms for prospective models other than the BSM are currently under development (Anderson, pers. comm.). Implementation of the mechanism by which passage models are linked to prospective life cycle models has yet to be resolved. Some issues to consider are:

- how to run forward projections with the passage models (e.g. use future flow projections to assign the most similar recent year from passage model runs)
- how will prospective life cycle models interact with passage models to calculate historical and recent scenarios
- what level of post-Bonneville mortality should be added to passage model estimates of fish survival
- how will passage-prospective model interactions work for drawdown scenarios

## Task 1.3 - Identify Uncertainties

The major uncertainties related to hydro actions involve the effects of the hydro system on juveniles both during their downstream migration (including the effects of both passage through and transportation around the hydro system) and any residual effects in the ocean. To facilitate the selection of uncertainties to explicitly consider in the decision analysis, we have identified a hierarchy of three levels of hydro-related mortality processes as modeled by the two passage models, CRiSP and FLUSH (Figure 1). The processes defined by these three levels provide a focal point for identifying the uncertainties that should be represented explicitly in the decision analysis (i.e. shown as uncertainty nodes in the decision tree). Note that there may be uncertainties not only in the current values or structure of these components, but also in how these components are expected to respond to the hydro actions under consideration. Both of these uncertainties should be considered in developing the decision framework.

NOTE: The Level 1, 2, and 3 nomenclature used here is not intended to correspond with the Level I, II, and III Hypothesis Framework used by PATH.

Level 1: At the most general level (Level 1) are the three major components of passage mortality in CRiSP and FLUSH: reservoir mortality, dam passage mortality, and transportation mortality.

Level 2: Level 1 components are composed of various sub-components of mortality. For example, reservoir survival is a function of flows, WTT, FTT, predation mortality, and gas-related mortality; dam passage mortality is made up of turbine, spillway, and bypass mortality. These sub-components form the second level of hydro-related mortality. Because Level 2 mortality processes are modeled differently by the two passage models, uncertainties in these processes will also be different.

Level 3: The third level is represented by the precise nature of the functional relationships and equations that are used in the models to represent Level 2 processes of hydro-related mortality. For example, FLUSH uses a relationship between FTT and survival to model reservoir survival rates, while CRiSP uses a series of equations describing gas-related and predation mortality processes. The result is that the survival-FTT relationships are quite different between the two models (FY96 Retrospective Report, Fig. C6A5-5).

Uncertainties associated with these Level 3 processes arise from three sources:

1) Uncertainties in the overall form of the relationship (e.g. is the relationship linear, exponential, logistic, etc.). These uncertainties should be considered explicitly where the main source of uncertainty is in the overall shape of functional forms rather than in their exact parameterization, or where the effect of a management action is expected to alter the general form of relationships. Lack of data with sufficient contrast (e.g. transportation vs. WTT studies) can result in this type of uncertainty.

2) Uncertainties in the parameters that determine the shape of a given functional relationship. These uncertainties should be considered where the functional relationship of a particular relationship is generally accepted, but the exact shape of that relationship as described by its parameters or the underlying data set is uncertain, or where the management actions are expected to affect one or more individual parameters in a relationship. Note that uncertainties in the functional form of relationships can be represented by changes in equation parameters to the extent that the relationship is flexible enough to represent the full range of uncertainty in its shape (e.g. stock-recruitment equation used in the BSM model accommodates different levels of depensatory mortality).

3) Uncertainties about which data sets or points should be used as the basis for estimating/calibrating functional relationships and their parameters. These uncertainties should be considered where there are multiple data sets that could be used to fit a relationship (e.g. reach survival studies), or where there is disagreement over particular years of data because of the experimental design, the exact methods used to collect the data, or the potential effects of confounding factors (e.g. low/high flow years, change in hydro system operations or configuration).

In general, uncertainties in the decision tree should be as specific as possible (i.e. Level 3) because (a) alternative hypotheses at this level of detail are easier to represent quantitatively; and (b) it will allow the effects of these uncertainties on the performance measures to be more precisely understood. Obviously, explicitly considering every uncertainty will lead to an overly complex analysis. Consequently, it is important to only incorporate those uncertainties that are the most critical in determining the model outputs that affect the ranking of management actions. The sensitivity of the decision to other uncertainties that are not incorporated into the decision tree can be dealt with through sensitivity analyses (carefully scoped to avoid prolonged and unnecessary analyses). Note also that each Level 1 component of hydro-related mortality does not necessarily have to be represented in the decision tree, and that there may be more than one Level 2 and 3 mortality process represented in the tree for a given Level 1 process. The point to emphasize is that only those uncertainties that have the most effect on the performance measures should be represented in the decision tree.

To focus the discussion of uncertainties in the models, we have listed in Table 3 below some of the Level 2 and 3 mortality processes associated with Level 1 processes (i.e. reservoir, dam passage, and transportation mortality). Parameter names are shown in *italics* and are based on descriptions of CRiSP 1.5 (CRiSP Manual dated March 20, 1996) and FLUSH 4.6 (Spring FLUSH Version 4.6, Draft Documentation. August 25, 1995). Page numbers in parentheses refer to these documents, except where otherwise noted. This list is not exhaustive but instead attempts to identify the only the most important processes in the models that correspond to the different levels of uncertainty. Updates and corrections to the information in the table are welcome.

Table 3. Hierarchy of components of hydro-related mortality

| Level 1 Component | Level 2 Component | | Representation of Level 3 component in CRiSP | |
|---|---|---|---|---|
| **Reservoir Mortality** | Flow | | flows provided by Hydro reg modeling group | |
| | WTT | | models to try to use similar WTT (March 4 hydro meeting) | |
| | FTT | | models to try to use similar FTT (March 4 hydro meeting) | |
| | Survival vs FTT - implicitly includes: gas mortality, predation, cumulative effects of migration delay (e.g. energy depletion, temperature effects, osmoregulation) | Functional form | not directly applicable to CRiSP | Survival vs. FTT |
| | | Parameters | | *A*, *B* (Ch. 6, App. 5)<br>*C* (under consideration) |

| | | | | |
|---|---|---|---|---|
| | | Data | | NMFS Reach Survival studies, 1970-1980 (excl. 1971-72)<br><br>1993-1996 NMFS PIT-tag data |
| | Gas mortality | Functional form | Gas mortality function | not directly applicable to FLUSH |
| | | Parameters | *a*, $N_S$, $N_C$, *b*, *H* (p. 86) | |
| | | Data | Dawley et al. (1976) | |
| | Predation | Functional form | Predation mortality function: | User-defined adjustment to *ResSurv* (p. 14) |
| | | Parameters | *a*, *P(E)*, *u*, (p. 66) | |
| | | Data used to parameterize/ calibrate | JDD Predation studies, 1984-1986; Predator Index studies, 1990-1993 ; Rieman & Beamesderfer 1990; Predator consumption study (Vigg et al. 1991) | |
| **Dam Passage Mortality** | Turbine mortality | Functional form | Turbine survival function | Turbine survival function |
| | | Parameters | *p*, *y*, *S*, *F*, $m_{fo}$, $m_{tu}$, *fge* (p. 135) | *Spillef*, *FGE*, *TurbSurv* (p. 15) |
| | | Data used to parameterize/ calibrate | PIT-tag estimates 1993, 1995; Inflated tag estimates 1993-94 (RMS and Skalski); | |
| | | Other data sets available | Turbine survival (Ch. 6):<br>PIT-tag estimates 1993, 1995;<br>Balloon-tag estimates 1994-95;<br>pre-1993 turbine survival studies (reviewed by Iwamoto and Williams 1993) | |
| | Spillway mortality[1] | Functional form | Spillway survival function | Spillway survival function |
| | | Parameters | *p*, *y*, *S*, *F*, $m_{sp}$ (p. 137) | *Spillsurv*, *Spillef* (p. 14) |
| | | Data | | |
| | Bypass mortality[1] | Functional form | Bypass survival function | Bypass survival function |
| | | Parameters | *p*, *y*, *S*, *F*, $m_{by}$, *fge* (p. 136) | *Spillef*, *FGE*, *Bypasssur* (p. 15) |
| | | Data | | |
| | Spill Efficiency | Functional form | *y* = Seven possible equations | assumed 1:1 at all projects except Dalles (function of spill proportion at Dalles) |
| | | Parameters | *a*, *b* (p. 119) | |
| | | Data used to parameterize | Hydro acoustical studies | |
| | | Other data avail. | Ch. 6 Appendix 4: Radio telemetry, experimental digitally-coded tags | |
| | FGE | Data used to parameterize | Snake R. PIT-tag data, 1989-1995 | NMFS estimates (Fisher 1993) |
| | | Other data avail. | Ch. 6: Fyke net estimates, 1989-93 | |
| **Transport. Mortality** | Barge mortality[2] | Functional form | Transport survival function | |

| | | | | |
|---|---|---|---|---|
| | | Parameters | $p, y, S, F, m_{fo}, m_{by}, fge, m_{tr}$ (p. 136) | |
| | | Data avail. | limited observations of direct barge mortality | |
| | Total mortality | | See discussion under Section 2.2.1 below | |
| | Proportion transported | Function of flows, FTOT rules | | |

1. Chapter 6 suggests that current values of these mortality rates are known with relative certainty (2%).
2. Barge mortality is assumed to be low (2-4%, Chapter 6), but there are few good studies.

**Task 1.3.1 - Identify Key Uncertainties**

Discussion of critical uncertainties at the Kah-Nee-Ta workshop indicated that the greatest uncertainties were those that related to:

a) reservoir survival
b) differential survival of transported/ non-transported and upstream/downstream fish below Bonneville Dam (post-BON survival)
c) uncertainties in the duration of the transition period between implementation of drawdown and restoration of “normal” river conditions, the possible effects on salmon stocks during the transition period, and juvenile survival rates under equilibrated (longer-term) conditions

These uncertainties are shown in Figures A1-1 and A3-1.

**Task 1.3.2 - Representation of Reservoir, Post-BON survival**

Task 1.3.2.1 - Representation of alternative hypotheses for reservoir survival

Alternative hypotheses for reservoir survival can be represented as different values of relevant parameters in the passage models (Table 3). For FLUSH, these parameters are *A* and *B* in the reservoir survival: FTT relationship; relevant parameters in CRiSP include the predator activity coefficient *a*, and the predator density *p(E)* (see Figure A1-1; only two hypotheses for each model are shown for simplicity). The same approach can be used to represent uncertainties in the response of reservoir survival to drawdown actions (Figure A3-1; hypotheses are represented by R1 and R2).

Different values of these parameters will produce different estimates of passage mortalities, which would then be used in the prospective life-cycle model (e.g. using Linkage Option 1 or 2 if BSM is used). Methods for assigning probabilities to alternative parameter values are discussed in task 1.4 below.

Task 1.3.2.2 - Representation of alternative **hydro-related** hypotheses for post-BON survival

A number of hydro-related alternative hypotheses for survival of transported ($S_T$) and non-transported ($S_N$) fish were identified at the workshop:

$H_1$: $S_T$ = F(WTT) - e.g. alternative transportation models used in Ch. 5 based on TCRs of 1.6:1 in 1986, 3.0:1 in 1977
$H_2$: $S_T$ = F (arrival time in estuary relative to spring transition)
$H_3$: $S_T$ = constant
$H_4$: T:C = constant (not pursued; group felt hypothesis did not warrant further analysis)
$H_5$: T:C =1/$S_N$, Direct (based on data from Raymond), equal post-BON mortality of transported and non-transported fish

These hypotheses can be represented by including them in alternative formulations of the passage models, depending on which prospective life-cycle models are used to forecast outcomes and how the passage models are linked to the prospective models (Figure A1-1; general hypotheses about post-BON survival under drawdown are shown as D1, D2 in Figure A3-1).

Task 1.3.2.3 - Representation of **non-hydro related** hypotheses about post-BON survival

Non-hydro related hypotheses will have to be dealt with outside the passage models, since CRiSP and FLUSH simulate only the effects of the hydro system (see Figure A1-1). Development and description of some non-hydro hypotheses are contained in the document by Williams et al. "The Columbia River Hydropower system: Does it limit recovery of spring/summer chinook salmon?", scheduled for submission to the SRP at the end of June.

**Integration of hypotheses of post-BON mortality into BSM**

Using the BSM model and Linkage Option 1 (passage models supply absolute survivals of transported and non-transported fish), hydro-related hypotheses would be explicitly incorporated into estimates of $S_T$. This was the approach taken in the 1995 Biological Opinion, where alternative hypotheses about transportation (variations on $H_1$) were used to derive estimates of overall survival of transported fish, including any hydro-related post-BON mortality. Using Linkage Option 2, alternative hypotheses would be represented by adjusting the ratio of $S_T$:$S_N$ and transport proportion $P_T$ supplied by the passage models. Although these statistics are sufficient to link the BSM to passage models retrospectively, more input to the BSM is needed for prospective simulations of consequences of management actions. The passage models would need to provide estimates of $S_T$, $S_N$ ,and $P_T$ . The BSM would use the survival ratio and transport proportion to scale the input survival fractions to fractions which include common delayed mortality, say $S_T$(BSM) and $S_N$(BSM). The common delayed mortality rate in a given year is given by

$$[\text{delayed mortality rate}] = \ln[S_T] - \ln[S_T(\text{BSM})]$$

There were two hypotheses about the delayed mortality discussed at the last workshop (H1 and H2) and one suggested by an internal PATH reviewer (H3):

H1: delayed mortality rate is proportional to direct passage mortality rate. Define the proportionality constant for transport fish -- let

$$\text{alpha}_T = [\text{delayed mortality rate}] / \{-\ln[S_T]\}.$$

Under H1, if transport survival is changed by management action to $S_T$(new), then the delayed mortality rate would be changed to [$\text{alpha}_T$ ]* $S_T$(new) and the BSM would simulate a transport survival :

$$S_T(\text{BSM new}) = S_T(\text{new}) * \exp( - \text{alpha}_T *\{-\ln[ S_T(\text{new})]\}).$$

Note that even though the BSM scales survival of transported and non-transported fish by a common delayed mortality rate, management actions result in differential delayed mortality between these two groups. Similar calculations would be applied to calculate consequences of management actions for non-transported fish.

H2: delayed mortality rate is independent of direct passage mortality rate. Under this hypothesis, if transport survival is changed by management action to $S_T$ (new), then the delayed mortality rate would not be changed and the BSM would simulate a transport survival :

$$S_T(\text{BSM new}) = S_T(\text{new}) * \exp( - [\text{delay mortality rate}])$$

Clearly the consequences of the alternative hypotheses are potentially very different new survivals for the prospective analysis.

H3: delay mortality rate is **inversely** proportional to direct passage mortality rate. This hypothesis would be seen if there is a proportion of the fish that have acquired a terminal disease or genetic condition prior to migration post-Bonneville (i.e. they are basically swimming morts destined to die regardless of improved passage conditions), or there is a threshold carrying capacity or predation limiting population level post-Bonneville (i.e. more fish below Bonneville results in a higher post-Bonneville mortality rate).

One possibility for inclusion of non-hydro hypotheses into the BSM model is to apply a magnification factor to the year-effect for upstream stocks to reflect hypotheses about regional differences in sensitivities to ocean conditions, and apply this adjusted year-effect in the stock-recruitment structure in BSM.

**Integration of hydro-related hypotheses into other prospective life-cycle models**
Mechanisms for incorporating transportation hypotheses into other prospective life-cycle models are currently under development.

**Task 1.3.3 - Identify uncertainties related to drawdown**

Uncertainties that affect the outcome of drawdown actions are shown in Figure A3-1. In addition to uncertainties in reservoir survival (or in the effects of drawdown on reservoir survival) and post-BON survival, the hydro sub-group identified three other major uncertainties specific to drawdown:

1. To what level will survival rates return to after drawdown?

A recent meeting of the PATH drawdown workgroup identified three potential approaches for determining a range of plausible “equilibrated” survival rates (i.e. after the river has returned to some equilibrium condition; S1, S2 in Figure A3-1).

a) Use survival data from pre-dam or currently unimpounded reaches.
If it is assumed that the juvenile survival rates of Snake River stocks prior to the development of Snake River dams represents the upper bound of survival rates that these stocks could achieve

after drawdown, then post-drawdown survival rates can be represented as some fraction of this upper bound. Information sources for establishing this survival fraction include:

- survival from pre-impoundment period
- WTT, WTT:FTT relationships, PIT-tag recoveries in unimpounded reaches (both upper and lower river)

b) Use natural river configurations of passage models to predict effects of drawdown on survival. This will require predictions of how flows, Water Travel Time, and Fish Travel Time would be affected by drawdown of Snake River dams. CRiSP would also require an estimate of changes in predator density, predator activity, and temperature.

c) Develop detailed mechanistic models (e.g. bioenergetic models, predator population models) to predict the effects of drawdown. This is a longer-term approach requiring considerable effort, although some of these models are already under development by the U.S. Corps of Engineers.

2. How long will it take for survival rates to reach some equilibrated level after drawdown?

If the decision is made to drawdown the Snake River dams to natural river levels, there may be a significant time lag before the actions are implemented because of delays in Congressional approval and funding, and engineering time constraints. Once drawdown is implemented, it may take some time for the river to return to what are considered to be natural conditions because of sediment releases from drawndown reservoirs, changes in thermal conditions, alteration of flow patterns, etc. Together, these two time intervals will determine how long it takes before some equilibrated level of survival is reached (E1, E2 in Figure A3-1; note that the “implementation interval” and the “natural river” interval could also be represented as separate nodes on the decision tree).

Uncertainties in the length of time it takes to reach an equilibrated survival level is important because the Jeopardy Standards have limited time horizons (24, 48, 100 years). Therefore, any delays in the restoration of “natural” river will reduce the probability of observing the biological response of these stocks to drawdown within a fixed time horizon. Information sources for specifying a range of potential transition periods, and the uncertainty within this range, include case studies from other drawdowns, hydrological models, and the judgment of those familiar with the Congressional process (e.g. personnel in the U.S. Army Corps of Engineers).

3. What will happen to survival rates during the recovery period?
Conditions in the river may change significantly between implementation of drawdown and return to normal conditions. These changes in conditions (and in the variability in those conditions) will affect fish populations (e.g. drawdown may lead to a short-term increase in turbidity; this may affect the natural mortality of fish in the river, or reduce predation rates), and the magnitude and direction of these biological effects in the interim period may have an important effect on the simulated Jeopardy Standards and consequently on the relative ranking of action A3. Potential sources of information for estimating possible effects (V1, V2 in Figure A3-1) and their uncertainties include case studies of other drawdowns, existing passage models, more detailed mechanistic models of predation, siltation, hydrology, etc. (if completed by October), and expert judgment. The PATH drawdown workgroup has not yet addressed this question.

**<u>Task 1.4 Probabilities</u>**

The assignment of probabilities to alternative hypotheses is a critical but difficult component of a decision analysis of hydro actions. The exact method that is used will depend primarily on the availability of data sets for assigning probabilities. These data sets must be truly independent or out-of-sample to provide a fair assessment of the relative probabilities of alternative hypotheses. For example, particular transportation studies have been used to calibrate transportation mortalities used in the models. As a result, predicted transportation mortalities will of course compare favorably to the observed values from which the predictions were derived. However, this apparent good fit, and the high probability that would result, is artificial and masks the uncertainty in the underlying data.

It is important to note that even data sets that are known to the modelers but were not used directly in model formulation (e.g. spawner-recruit data) may not be independent because these data may have indirectly influenced the development or calibration of the models. Thus, there may be few or no truly independent data available to assign probabilities. This issue has yet to be resolved.

Other considerations exist when alternative hypotheses are expressed as alternative forms of models. In these cases, care must be taken to distinguish between model "calibration" and model "validation" when fitting models to data. Neither exercise may be suitable for assigning probabilities to alternative models. Appendix A by Randall Peterman provides more detailed discussion of this issue.

To help focus the discussion, we present three potential approaches for assigning probabilities to the alternative hypotheses displayed in the decision tree.

**Approach A: Use spawner-recruit data and MLE model to assign probabilities.**
This approach is relevant to Linkage Option 1. Have the models simulate a unique vector of passage mortalities using each possible "chain" of alternative hypotheses for the different uncertainties (e.g., the combination of A1, FLUSH *A1, B1*, and Trans. H1 in Figure A1-1 forms one chain). Then, run these vectors for all branches through the MLE model to obtain their relative probabilities (P1 in Figure A1-1) based on how well the hypotheses in each chain fit the spawner-recruit data.

Models 13-16 in Ch.5 of the retrospective analysis report provide the basis for an example of this option. These models use different combinations of the two passage models and two hypotheses about the post-BON survival of transported and non-transported fish (T1 and T2, which are different variations on hypothesis H1 in task 1.3.2.2 above) as inputs to the MLE model, which then calculates their likelihoods. These likelihoods, when raised to a power and then scaled relative to one another, can be used to derive posterior probabilities for these 4 models[1].

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[1] Theoretical support for this approach comes from the following:
The relative probability of a given chain of hypotheses or "Model" (say $M_j$) is given by Bayes Theorem:

$$P(M_j \mid D) = P(D \mid M_j)\, P(M_j) \,/\, [\, \Sigma_k\, P(D \mid M_k)\, P(M_k)]$$

where

$$P(D \mid M_j) = \Sigma_\theta\, P(D \mid \theta, M_j)\, P(\theta)$$

is the marginal likelihood of model $M_j$. The $\theta$ is the vector of parameters estimated by MLE for the model, P() stands for probability, and "D" is the stock-recruitment data. The "prior" indication of weight for a given chain is the $P(M_j)$ term. If the alternative models have the same number of parameters and uniform priors are assumed for the $P(\theta)$ then $P(D \mid M_j)$ is approximately proportional to the likelihood evaluated at MLE raised to the [(n-k)/n] power

Although in this example only one uncertainty is considered (post-BON survival of transported and non-transported fish), the same approach could be used to assign probabilities to combinations of more than one uncertainty. For example, separate passage model runs could have been done using one of three hypotheses about reservoir survival (e.g. three values of *a* in CRiSP, three values of *B* in FLUSH) in addition to the two hypotheses about post-BON mortality for a total of 12 different vectors of passage mortality estimates. Probabilities obtained by running these 12 vectors through the MLE would reflect the relative probability on each combination based on their fit to the spawner-recruit data.

A potential disadvantage of this approach is that because the spawner-recruit data and the MLE analysis have been available for some time, it may not be possible to get versions of CRiSP and FLUSH that have not been influenced (either directly or indirectly) by the MLE. Thus, the spawner-recruit data may not be a truly independent data set. One possible way around this problem is to use the comparisons to the MLE to guide subjective assignments of probabilities to alternative hypotheses rather than use them quantitatively (see Approach C below). Also note that this option cannot be used if BSM/Linkage Option 2 is used, because this option scales the passage model output to exactly match the spawner-recruit data. Therefore, each chain of hypotheses will fit these data equally well.

**Approach B: Use other data sets to assign probabilities.**
There are a number of other data sets that are relevant to survival of fish in specific components of the JMC life stage. Examples include data from predator studies, FGE estimates, transportation studies and reach survival studies. Using this approach, these data sets could be used to derive probabilities for specific alternative hypotheses. For example, assume that there are several possible survival-FTT relationships that could be fit to a given set of reach survival data. Relative probabilities that reflect the relative fit of these relationships to the reach survival data could be estimated. These probabilities could then be used either alone or combined with probabilities for hypotheses in other uncertainty nodes to derive a probability for an entire chain of hypotheses leading from management action to outcome.

Note that approach B does not use the spawner-recruit data to assign probabilities, avoiding the potential problems associated with the influence of these data on development of the passage models. However, this approach may suffer from the same problem of lack of an independent data source if care is not taken to avoid using the same data sets to both calibrate (parameterize) and validate (assign probabilities) to the models.

This approach could be used with either Linkage Option 1 (and either BSM or some other prospective life-cycle model with a passage mortality component) or BSM/Linkage Option 2. For the first option, the probabilities could be used as a prior probability in conjunction with the likelihoods calculated using the MLE model to derive posterior probabilities (i.e. P1 in Figure A1-1). P1 would thus reflect both the fit of the vector of passage mortalities to the spawner-recruit data AND the fit of the hypotheses included in that chain (e.g. survival-FTT relationships) to the other data sets (e.g. reach survival data).

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where k is the number of parameters estimated by MLE, excluding the variance. The proportionality constant is the same proportionality constant for each model; the approximation is based on a Laplace's method (Gelman et al 1995) .

For the second option, the probabilities based on other data sets would be combined into an overall probability for the ratios of $S_T$:$S_N$ produced from each chain of hypotheses. For example, P2 in Figure A1-1 for the FLUSH *A1 B1* : Trans. H1 chain of hypotheses would therefore equal the probability calculated for FLUSH *A1, B1* multiplied by the probability calculated for Trans. H1.

There are several ways to assign probabilities using other data sets, including subjective assignment, or a Bayesian approach (i.e. likelihood estimation, calculation of posterior probabilities). At the last workshop, the hydro sub-group discussed several options for applying Approach 2 to quantify the uncertainty in reservoir survival:

1. Assess alternative forms of FLUSH and alternative forms of CRiSP independently using different data sets. For example, alternative hypotheses for reservoir survival for FLUSH might be derived from fitting curves to alternative data sets, while for CRiSP alternative reservoir survival hypotheses might consist of different values for the *a* parameter in the predation mortality equation, based on uncertainty in the underlying data from predation studies. This approach would not allow for comparisons of hypotheses across models, only within models.

2. Compare observed reservoir survival to predicted reservoir survival for CRiSP and FLUSH. This option is not feasible, since there estimates of reservoir survival are generally derived from reach survival data and dam passage mortality data, both of which are used to calibrate the models.

3. Compare observed reach survival to predicted reach survival for CRiSP and FLUSH. This option was rejected as a means for assigning probabilities because of the issues discussed under task 1.2.4 above.

4. Compare alternative functional forms of reservoir survival vs. FTT or WTT (including explicit FLUSH relationship and implied CRiSP relationship). This is straight forward for FLUSH but not for CRiSP because reservoir survival in CRiSP is the composite of predation and gas-related sources of mortality in the reservoir, and thus does not contain an explicit reservoir survival vs. FTT relationship. In addition, CRiSP and FLUSH operate on different temporal scales ( FLUSH - seasonal average, CRiSP daily), making direct comparisons difficult.

5. Monte Carlo approach - for each run of the passage models, randomly sample from distribution of all or a subset of parameter values in the models, then compare the resulting predicted reach survival to observed reach survivals and calculate a likelihood for that particular combination of parameter values. Sample many times to obtain posterior distribution of values for all parameters, then sample from these posteriors in BSM and integrate to get expected values of performance measures. For models with equal prior probabilities, the equations would be:

$$
\begin{aligned}
P(M1|D) &= P(D|M1) / \ \Sigma P(D|Mi) \\
P(D|M1) &= P(D|M1,\theta 1)P(\theta 1)d\,\theta \\
&\approx 1/N \ \ \Sigma P(D|M1,\theta\, i)
\end{aligned}
$$

**Approach C: Use expert judgment to assign probabilities.**

This approach relies on the judgment of experts to assign probabilities to alternative hypotheses and can be used to complement other approaches in cases where there are no data (as will likely be the case for uncertainties related to drawdown) or where existing data are judged to be inadequate or not sufficiently independent to warrant a quantitative assessment. In the latter case, existing data can still be used as an information base for assigning subjective probabilities. A critical component of this method is a sensitivity analyses to determine how sensitive the ranking of the different actions is to probabilities assigned by different experts or sets of experts.

Formal techniques for eliciting the judgments of experts are available to help with this approach. The following primer on formal expert judgment was provided by Robin Gregory, an expert in these techniques:

A formal expert judgment process is defined as a structured process for eliciting opinions form selected experts and for documenting them for others to evaluate, Formal expert judgment processes are useful if models are inadequate, if a technical question is both important and complex, if data are unavailable, and if there is significant scrutiny regarding these judgments.

The primary uses of decision analysis in eliciting expert judgments are to decompose the uncertain subject matter, to quantify judgmental probability distributions for the decompositions, and to re-aggregate the elicited probability distributions using probability theory. A comprehensive expert judgment should include the following steps:

1. Formulation of the technical question that is to be answered
2. Selection of the experts
3. Training of the experts regarding process and judgmental biases
4. Decomposition of the technical question
5. Elicitation of probability distributions
6. Recomposition of and aggregation across expert opinions
7. Documentation

These steps are adapted to the special needs of the study at hand; not all of these may be necessary in PATH. In many cases, the process of clearly structuring the question (step 1) can lead to new insights for model development, as can expressed differences across experts in their views of the components of the technical issue (step 4). Techniques such as influence diagrams, knowledge maps, or decision trees can provide helpful visual depictions of the results of these steps. The advantages of using a formal expert judgment process include improved accuracy, improved consistency, improved dialogue among experts, and improved documentation of the methodology and elicitation process. Potential disadvantages include the required allocation of resources and the unfamiliarity of substantive experts with the benefits of a formal judgment process.

References include the following:

Howard, R. 1989. Knowledge maps. Management Science 35: 903-922.

Keeney, R.D. and D. Von Winterfeldt, 1991. Eliciting probabilities from experts in complex technical problems. IEEE Transactions on Engineering Management.

Spetzler, C. and C.A. Stael von Holstein. 1975. Probability encoding in Decision Analysis. Management Science 22: 340-352.

## Task 1.5 - Calculate Performance Measures

Primary performance measures for evaluating hydro actions will include NMFS Jeopardy Standards, harvest statistics, and others that have yet to be defined. Concepts in the ISG (now the ISAB) “Return to the River” report provides another potential source of performance measures. Although this report is prescriptive in nature, it contains hypotheses that may imply some performance measures. In addition to these primary measures, we suggest that a number of intermediate “diagnostic” performance measures also be produced (e.g. dam passage mortality, reservoir mortality) to better understand differences in the primary performance measures.

## Task 1.6 - Apply criteria and rank actions

The end result of the decision analysis will be a ranking of the alternative actions, according to the criteria selected. Sensitivity analyses will then be necessary to show how these rankings change in response to changes in some of the assumptions and components described above.

A key question is how to display the results of the decision analysis. Applying multiple criteria to rank management actions creates the potential for cases where different criteria lead to different rankings of management actions. There are methods such as multi-attribute utility theory that could be used to combine multiple criteria into a single value and thus produce a single ranking of alternative actions. However, this approach will mask the trade-offs between criteria that will have to be made to make a decision. It will be critical to display the results of the decision analysis in such a way that the implications of selecting different criteria for the recommended decision are clear to everybody (scientists, managers, politicians) who will be using these results. A multiple accounts type of approach, in which the different rankings of the actions are explicitly compared in a tabular form, is one way to do this.

Another consideration in the display of results is how the results of analyses of other aspects of the decision (e.g. economic considerations) will be displayed. Similar ways of displaying the results of the biological, economic, and other analyses will help decision-makers integrating all of these factors in their decision.

**Figure 1. Hierarchy of mortality processes**

Level 1.

| | | |
|---|---|---|
| Major Component<br><br>Reservoir Mortality | Major Component<br><br>Dam Passage Mortality | Major Component<br><br>Transportation Mortality |

Level 2.

| | | |
|---|---|---|
| Sub-components<br><br>flows, WTT, FTT, predation, gas mortality | Sub-components<br><br>turbine, spill, bypass, spill efficiency, FGE, spill caps | Sub-components<br><br>barge mortality, total mortality, proportion transported |

Level 3.

| | | |
|---|---|---|
| Model Representation<br><br>Res. Surv vs. FTT - FLUSH<br>Gas; predation - CRiSP | Model Representation<br><br>turbine survival, bypass survival, spillway survival functions | Model Representation<br><br>transportation survival functions, flows, FTOT (EC) rules |

| |
|---|
| Uncertainties<br><br>- form of relationship<br>- parameter values<br>- data sets |

## Appendix A. Assigning Probabilities to Alternative Models (Randall Peterman)

Dear colleagues,

I apologize for not getting back to you much sooner concerning the document that Rick Deriso, others, and I were supposed to draft concerning placing probabilities on alternative models in the PATH decision analysis. I have been tied up with other urgent deadlines.

Rick and I talked at length about this topic on the drive back to the Portland airport after the April meeting at Kah-Nee-Ta, and I understand that he had some input to a draft document that already includes a section on this topic: Peters, C., D. Marmorek, and R. Deriso. 23 May 1997 draft of "Alternative structures for a hydro action decision tree." The section in that document, "Task #1.4, Probabilities" covers the issues reasonably well that we came up at the meeting in April, particularly in the Hydro subgroup. I only have a few comments to add, and these also take into account two other documents:

1. Anderson, J., C. Paulsen, and R. Hinrichsen. 13 May 1997. Comparison of MLE spawner-recruit models.
2. Deriso, R. 16 May 1997. Comments on - Comparison of MLE spawner-recruit models.

After talking to Calvin, we concluded that the best thing to do at this late date would be for me to provide comments on these three PATH documents.

General Comments

As a preview, I do not have a simple, magic answer. There are still things that can be done, but the emphasis on the freshwater life stage and the history of "tuning" that has occurred with these models precludes most of the standard methods for placing probabilities on them for a decision analysis.

My comments generally relate to the nature of models and their uses. All of you are probably aware of these points, and I definitely don't want to sound paternalistic, but some of these ideas appear to have been forgotten under the pressures involved in the Columbia River salmon situation. About half of you heard these ideas when I gave a short presentation to the Hydro subgroup on the last day of the April PATH meeting.

The decision analysis is only going to be useful if a wide range of alternative hypotheses are considered. Too narrow of a range will produce overconfidence in the resulting ranking of management options.

The ultimate goal, as I understand it, is to determine which management actions will be most effective at increasing recruits/spawner, because this will improve the chance of abundances increasing. So how do we determine which models are best for doing this?

The first issue is to distinguish between "calibration" and "validation" of models. Much has been written on this topic by various authors in the general modeling literature, but some of it is misguided. Models are nothing more than quantitative descriptions of hypotheses. In order to make progress in science, we have been trained to erect and test alternative hypotheses. That means we first we need true alternatives, which means alternative models (to the extent that they might be qualitatively different hypotheses or even just one set of code but with a different value for some parameter in each alternative). We should not push any one particular computer model any more than we should push one particular verbal hypothesis about why one fish stock crashed while another did not, for instance. Instead, we should be open to letting data and future experiments modify our degree of belief in the alternative hypotheses. To some extent, both "calibration" and "validation" basically aim to increase the degree of belief in one or more hypotheses, while decreasing our belief in others.

In the specific case of the different "labelled" salmon models (CRiSP and FLUSH) and their many variations, "calibration" occurs when parameters are "tuned", or new sub-hypotheses added, in order to get the model to best reflect some data. This has apparently been done by both modeling groups, and apparently in some cases with different data sets. The fact that each model can represent the same data set reasonably well with quite different hypotheses about mechanisms, should immediately raise red flags of caution. This is a classic example of "equifinality," or getting to the same end result by different means. The fact that the same endpoint is found says little about the degree of belief that one should place in one model or another. This is because the models have so many degrees of freedom that it is possible to tune them reasonably well to any given set of data. For this reason, we <u>cannot</u> use as the probabilities in the decision tree for the different branches, the extent to which the different models "fit" the data (with whatever fitting measure you use). This is true even if the same data set is used to tune each model. The lack of independence of the input and output data makes the calibration process circular. While it may be <u>necessary</u> that there be reasonable agreement between historical data and model output, the magnitude of that agreement is <u>not sufficient</u> justification to use that model for forecasting new situations. In effect, comparison of alternative models only at this level constitutes a weak test of their value.

Instead, each model (sets of hypotheses) should be subjected to a variety of "strong" tests before concluding that the degree of belief in their usefulness is high enough to use in decision making. That is the goal, to find the approaches (models -- note the plural here) that will give the most confident forecasts of future recruits/spawner under a differently managed system. This is an extremely important distinction from the model "calibration" process. In the calibration, even if all models are equally good at reflecting historical data for one or more life stages, that says very little about how effectively they will forecast effects of future management actions, because those actions are likely to take the system outside of the range of past conditions where there were data for "tuning."

Thus, in this model "validation" phase, we basically want to "set the alternative hypotheses at risk." Our goal is to "invalidate" some alternatives (I prefer this term to "validate" because it emphasizes that we have to deal with a range of alternatives, not just one "pet" model or hypothesis). So what constitutes a test of the alternatives? The short answer is, use completely new situations to see how the forecasted response compares to the actual observed one. We would prefer a field experiment, where certain factors are controlled and others manipulated in some experimental design. This was what PATH was originally aiming toward -- identifying appropriate experiments. But field experiments are obviously not possible in the short time available, so the next best thing is computer experiments. The models should be subjected to various "perturbation" experiments to determine whether they behave qualitatively correctly, as well as quantitatively, in completely new situations (e.g. extremely high water flows)? This would require bringing in completely independent data, not used in the previous calibration of the models. At the April meeting, someone mentioned the 1966-1969 data, which were prior to the Snake River dams. I did not see that mentioned in the three documents listed above. While these are only 4 data points, they might provide a diagnostic test that would provide information about the relative value of different sets of hypotheses (models). There may be others as well, and they may even have to come from non-Columbia River systems.

<u>Specific Comments on the three PATH Documents</u>

For these reasons, I do not like Approach A on page 13 of the document by Peters et al. "Alternative structures for a Hydro Action …" As the authors note, it still is not dealing with truly independent data sets from the ones used to calibrate the models. If probabilities were derived in this way, they would only reflect how effectively the models were "tuned."

If independent data sets are available, then one could use their Approach B (p. 13). Linkage Option 1 appears to be better than Linkage Option 2. However, even Option 1 suffers from the "tuning" problem by including vectors of passage mortalities.

I may have missed it, but I did not see in these documents the suggestion to focus on totally new management situations (like extreme water flows) in order to test the effectiveness of these models for forecasting recruits/spawner. This is where you might find that several sets of hypotheses behave completely unacceptably (lowering your degree of belief in them), while others do well (at least qualitatively). With independent data sets, such comparisons can be made quantitatively.

Approach C, to use expert judgment, may be a possibility if you can find people who are knowledgeable enough about the details of the Columbia River system, yet who have not been actively involved in the politically charged process over the last decade. I would not be surprised to hear that there is no such person, by definition!

The Anderson et al. document is very informative because it compares the structure of the existing models in a similar format to understand the differences in their assumptions. However, the Anderson et al. and the Deriso documents do not shed much light on the particular question about placing probabilities on alternative models. In effect, what Anderson et al. propose is yet another form of "tuning" or "calibrating" models that, aside from potentially suffering from over-parameterization, still will not indicate the degree of belief that we should place in each of these different models in forecasting future recruits/spawner under new conditions. So I basically agree with Deriso that developing further versions of such models by adding other independent variables will not head us toward our objective.

## Conclusion

As I forewarned, I have no "magic answer." Even placing equal probability on alternative models is not necessarily reasonable. Consider, for example, if I had drafted up some model and put it on the table to be included in the decision analysis If I had made some drastic error such that the forecasts of results were way off (and way different from the forecasts of the other models), then by placing equal weighting on my model and the other models, the expected value of the outcome, and ranks of management options, could become seriously biased. This is only a hypothetical extreme, but I hope the point is clear that while equal probability sounds like a reasonable compromise, the result of using it is potentially biased.

Perhaps all we can do at this point is use the decision analysis along with numerous sensitivity analyses to identify the range of parameter conditions in which some particular management action remains the optimal one. It will then be up to somebody to determine where in the ranges particular parameter values are likely to fall, and therefore which actions are most likely to be robust to uncertainties in parameter values.

At the very least, two valuable outputs from a thorough decision analysis will be: 1) identify future research priorities by determining which components most sensitively affect the rank order of management options, and 2) help resolve differences in viewpoints by identifying specifically which aspects of the analysis parties disagree about (e.g. parameter values), and determining how much that value would have to change to make the recommended action be the same for different interest groups. This role of decision analysis in conflict resolution has been useful. In some cases, only a small change in someone's parameter value is necessary for the recommended action to become the same for everyone. Let's hope it works out that way.